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PASSIVE DEHUMIDIFICATION AND AIR CIRCULATION VENTILATION SYSTEM FOR NORTHERN RURAL HOUSING IN ALBERTA

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PASSIVE DEHUMIDIFICATION AND AIR CIRCULATION VENTILATION SYSTEM FOR NORTHERN RURAL HOUSING IN ALBERTA

June, 1991

Prepared by:

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The views and conclusions expressed and the recommendations made in this report are entirely those of the authors and should not be construed as expressing the opinions of Alberta Municipal Affairs.

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FOREWORD

The project documented in this report received funding under the Innovative Housing Grants Program of Alberta Municipal Affairs. The Innovative Housing Grants Program is intended to encourage and assist housing research and development which will reduce housing costs, improve the quality and performance of dwelling units and subdivisions, or increase the long term viability and competitiveness of Alberta's housing industry.

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As the type of project and level of resources vary from applicant to applicant, the resulting documents are also varied. Comments and suggestions on this report are welcome. Please send comments or requests for further information to:

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EXECUTIVE SUMMARY

The main objective of this project was to explore innovative methods to control and reduce condensation problems in small wood heated houses in northern rural areas of Alberta. As now built and operated, these houses have limited or no mechanical ventilation, intermittent hand-fired heating systems, partially insulated and sealed exterior envelopes and high levels of occupant generated water vapour. Problems of severe condensation, mould and mildew propagation and degradation of finish and structural materials develop quickly in these houses. Since mechanical ventilation is limited or non existent, a need exists for development of a simple and cost effective moisture removal strategy; possibly one that is driven by such existing, cost-free forces as stack effect or differential wind pressures.

The work included the following tasks: literature review; discussions with research, construction and operating experts; study of mitigation strategies; theoretical studies of various design possibilities; laboratory testing and evaluation of potential alternate solutions and subsequently, proposals for retrofitting and field testing of moisture mitigation system(s) in houses in Chipewyan Lake and Peerless Lake, Alberta.

Occupancy loads and thus moisture generation in these houses vary widely from unit to unit and from time to time. Some houses are almost continuously occupied by a large number of adults and small children. Several wash loads of wet clothing may be hung to dry on interior clotheslines in these houses each day, adding greatly to the amount of moisture in the indoor environment.

In typical houses moisture generation can be from seven to 20 kilograms per day, depending on lifestyle and occupancy. Such amounts of water must be safely and economically extracted from the houses. While a typical exhaust fan could extract approximately 15 kilograms of moisture each day, fans are often prone to mechanical failure or are not used by residents due to their noise or perceived energy cost. The vapour diffusing panel concept presented in this report would be capable of extracting 15+ kilograms of moisture each day with no moving parts, limited chance of failure and little cost in terms of energy losses.

Based on the laboratory tests, it was concluded that it is possible to build a water vapour vent in both new and retrofit conditions which will exhaust the moisture generated in a typical northern home. Using oriented glass fibre insulation board, a typical collection of 12, 150 mm x 400 mm vents would exhaust approximately 17 kilograms of water per day. However, as the vents have only

been tested under controlled laboratory conditions, the report also recommends field testing and monitoring of a prototypical installation in an existing, humidity stressed home.

1.0 Introduction

Moisture in occupied buildings can be both a necessity and a hazard. Moderate humidity levels increase the comfort level and have been shown to be of benefit in combatting colds and other minor ills. However, excessive levels of humidity or high rates of moisture generation in buildings can lead to problems of moisture condensation within the structure or on the interior surfaces of poorly insulated buildings. Rot, mould and mildew propagation, surface wetting, frosting, staining, warping and delamination of building elements and assemblies are the usual results of such condensation and uncontrolled moisture movement within building envelopes in cold climates.

The bulk of the population in southern Canada is well served with housing that has evolved in the past few decades in an ongoing process which has improved construction practices as new knowledge, materials and methods have developed. For typical Canadian lifestyles, modern houses give generally satisfactory performance when constructed to average standards of quality and equipped with forced air heating systems. Design and construction technologies are in a relatively younger stage of development for the demanding climate, lifestyles and energy supply conditions prevailing for northern and remote housing in Canada. There continues to be widespread moisture related problems in northern housing where remoteness, lack of services, and extra capital or operating costs have deterred the adoption of mechanical heating, ventilating and dehumidification technologies.

Given the existing conditions, the purpose of this project was to explore alternate dehumidification strategies which were simple to operate, sturdy and cost effective. A starting point for the work was the preposition that whereas cold walls triggered condensation, albeit causing damage, if that process could be controlled and restricted, it might be a viable humidity reduction strategy. The explorations primarily dealt with the development, testing and evaluation of a wall mounted, passive, venting or condensation panels.

The scope of the work covers typical small northern homes, but focuses on solutions which are appropriate for new construction or retrofit application on the smaller (1000 sq. ft.) bungalows found in some isolated or reserve locations.

The report is divided into eight subsequent sections. Chapters 2, 3 and 4 deal with the literature review, discussions with knowledgeable practitioners, and site visits respectively.

Chapter 5 lists, and briefly evaluates, alternate dehumidification strategies while Chapter 6 provides a detailed, theoretical, mathematical analysis and evaluation of each one.

Chapter 7 outlines the laboratory tests which were conducted using the preferred option, and discusses the implication of the findings. Chapter 8 contains a proposal for transferring the laboratory work to a full scale, one year field demonstration on an existing home.

Chapter 9 contains the report conclusions.

2.0 Literature Survey

The study of moisture flow through building envelopes has been a popular item in technical and engineering journals and proceedings. Many papers discuss the detrimental effects of moisture condensation within the cavities and on interior surfaces of the building envelope. The application of building science principles to the enhancement of moisture flow, or moisture ejection from a building, has been documented less often.

The Division of Building Research (DBR) of the National Research Council and later the Institute for Research in Construction (IRC) have devoted many papers to the study of moisture flow through the building envelope. Their Canadian Building Digest (CBD) series has been used for the public presentation of research results from all areas of building science and all staff authors, and thus includes many applicable findings. It is interesting to note then, that many of the CBD's published in the first ten years, indeed even CBD 1, are on the topic of moisture in buildings, its effects on building performance and its control.

The first CBD by Dr. N.B. Hutcheon (1960) recognized that in buildings with large moisture sources, steps may have to be taken to eliminate water vapour. Problems associated with moisture condensation were identified early on in the investigative process. These included increased heat flow, deterioration of the structure, corrosion of fasteners and other metals, decay of sheathing, siding and other wood materials, paint and surface coating blistering, dimensional changes in the structure and differential movement, freeze/thaw degradation and aesthetics.

Water vapour moves through building materials and assemblies by two transport mechanisms: vapour diffusion and air leakage. Vapour pressure differentials provide the driving forces for vapour diffusion and air pressure differentials provide the driving force for air leakage. To combat problems of moisture deposition in the building envelope, two protective measures were conceived. First, the use of vapour retarders was recommended to impede moisture flow by diffusion. This was based in a large part on work done in Europe in the very early part of the twentieth century. Second, in the 70's, the need to control air flow through gaps and holes in the building envelope was recognized and recommendations were made to design buildings for airtightness. This was always recognized as a prime function of the building envelope, although for a time home builders concentrated on the provision of vapour retarders as the sole countermeasure against moisture deposition.

As building science progressed it was recognized that, by itself, vapour diffusion very rarely caused problems associated with moisture condensation, and was seldom a major contributor to moisture accumulation. Air leakage was identified as the prime vehicle for moisture transport into, and through, the building envelope as far back as the mid 1950's. An example of this was given by Latta (1976) in CBD 175. He described a relatively tight masonry and concrete block wall which developed a crack of only one sixteenth of an inch (1.5 mm) along each side. Using the calculations for diffusion and air leakage with only a small stack pressure, he demonstrated that air leakage carried six or seven times the moisture carried by diffusion, even though there was no vapour retarder to control diffusion.

Surface moisture condensation has long been a problem in Canadian buildings, due in part to low levels of thermal insulation. This most often occurred first on single and double glazed windows and in areas where curtains or furniture restricted heat flow to wall areas. The amount of condensation is dependant on the interior humidity level, the surface temperature of the wall or window and the amount of cooling or heat removal at the condensation site.

Handegord (1962) investigated the case of condensation and dripping in curling rinks in CBD 35. These were unique situations due to the lower temperatures in the curling rinks and the acceptance of some surface condensation, but such factors only opened up the possibilities for more innovative remedies. Four solutions were given in CBD 35. The first suggestion was to vent any condensate to the outdoors, particularly from the underside of the roof deck. It was recognized that this solution would be limited in colder weather due to the reduced ability of outdoor air to carry moisture. Handegord suggested passive ventilation if wind pressures were sufficient, or if stack pressures could be generated in the building. Mechanical ventilation would also provide humidity reduction, but at the cost of equipment and operation expenses. The second suggestion was dehumidification, using ventilation of the interior space with drier outdoor air or some form of refrigeration to remove moisture from the indoor air. It was suggested that cold sections of the walls could be used as moisture collecting surfaces. This would involve removal of condensate from the wall surface and cooling of the wall surface by outside exposure to continue the condensation process. The process of moisture removal by this means could also be enhanced by raising the interior temperature. The third solution to excessive surface condensation was to elevate the interior surface temperatures, either by increasing heat delivery to the surface on the warm side, or by reducing heat loss to the outdoors. The fourth solution was to use temporary absorption of the condensate formed during cold periods, and re-evaporation of the moisture when heat was again applied, either by exposure to solar radiation or by intermittent mechanical or electrical space heating.

The Division of Building Research concentrated on "Humidity, Condensation and Ventilation in Houses" in its 1983 Building Science Insight ("BSI'83") series of cross-Canada seminars, which consisted of four presentations. The first paper, by J. Rousseau of Canada Mortgage and Housing Corporation, discussed the types and extent of moisture related problems in the Canadian housing stock, from the perspective of CMHC. Five types of problems were identified: mould and mildew on interior surfaces, condensation on and around windows, condensation in attics, condensation in walls, and deterioration of exterior siding. Causes of the problems were grouped under interior conditions, climate and construction of the houses. It was found in a cross-Canada survey that the incidence of high interior humidity was a strong contributing factor to all problems. Cold weather was also a catalyst in causing problems, and in every case of moisture problems there was some contribution from poor or improper construction of the building envelope. Failures in the construction included incomplete air barrier systems, missing or low thermal insulation and insufficient ventilation, in the case of attic condensation. Ventilation in this sense is the dissipation of moisture away from deposition sites within the building envelope, not the exchange of indoor and outdoor air to reduce the indoor humidity level.

The second, third and fourth papers of BSI'83 were written by R.L. Quirouette, M.Z. Rousseau and G.O. Handegord respectively, all from IRC. The second paper, by R.L. Quirouette, discussed the sources of moisture within houses. Many of these sources occur in northern Alberta rural communities where problems of moisture condensation have become apparent. Many are occupant generated, such as cooking, bathing and clothes washing and drying. Some sources are not so apparent, however, such as drying firewood, which could release up to 250 litres of moisture per cord. Crawl spaces can be still another major source of moisture into the house. If the ground surface is exposed or there is ponded water in the crawl space, and the crawl space air is allowed to enter the house, it could bring in 40 to 50 litres of moisture per day. Quirouette also demonstrated that the movement of water vapour through a 1 mm diameter hole under a 10 Pascal air pressure differential is 100 times greater than the movement of water vapour as a result of vapour diffusion through the same 1 mm diameter hole.

The third paper of BSI'83, by M.Z. Rousseau, concentrated on the control of surface and concealed condensation, and discussed high humidity levels and/or low surface temperatures as causes of surface condensation. Concealed condensation was usually the result of a failed air barrier system and air exfiltration. The fourth paper, by G.O. Handegord, discussed ventilation requirements and processes in houses. The process of air leakage through cracks and openings in the building envelope was explained. He also discussed the operation of chimneys in houses and noted the draft up a chimney varied from five litres per second, for an airtight wood stove, to 70 litres per second for an oil furnace, and up to 200 litres per second for an open wood fireplace. The updraft pressure on the chimney could be higher than 50 Pa. Handegord discussed several ventilation appliances which are in common use, including exhaust-only fans and heat recovery ventilators (HRV's). He suggested a ventilation capacity of at least 75 litres per second for normal occupancy, although operation would probably be at a level below capacity. For excessive moisture generation due to high occupancy or other factors, the ventilation capacity and operation should be increased.

Condensation within walls and other building cavities may be accommodated without serious deterioration provided regular drying is allowed to occur. It is possible to design walls and other building components in a manner such that when condensation occurs, it does not lead to building envelope deterioration. Handegord (1983) proposed flashing the bottom of a stud wall filled with any self-draining insulation so that interstitial moisture within the wall cavity would be led out of the "draining" wall. An example of a self-draining insulation is any glass or mineral fibre insulation. Timusk and Lischkoff (1983) have shown that glass fibre insulating sheathing with a bonded air retardant membrane facing inwards performs better under extreme conditions of temperature and relative humidity than the same material with the membrane facing outwards. Exposed to an outdoor temperature of -20°C and an indoor relative humidity of 52 percent at normal room temperature, a test wall with the insulating sheathing and air barrier facing outwards trapped three times more moisture than a test wall with the membrane facing inwards. Unlike exterior sheathing board or insulating boards of low permeance, the membrane did not act as a condensing surface when placed on the warm side of the insulation. Lstiburek and Lischkoff (1984) further found that if the insulating sheathing were installed with the membrane facing outwards, as in a conventional installation, the potential for trapping interstitial condensation increases while the vapour permeability may tend to decrease due to the membrane becoming clogged with ice crystals, to the extent that it may act as a vapour retarder.

3.0 Discussions with Experts in Moisture Migration and Control With Respect to Residential Building Envelope Design

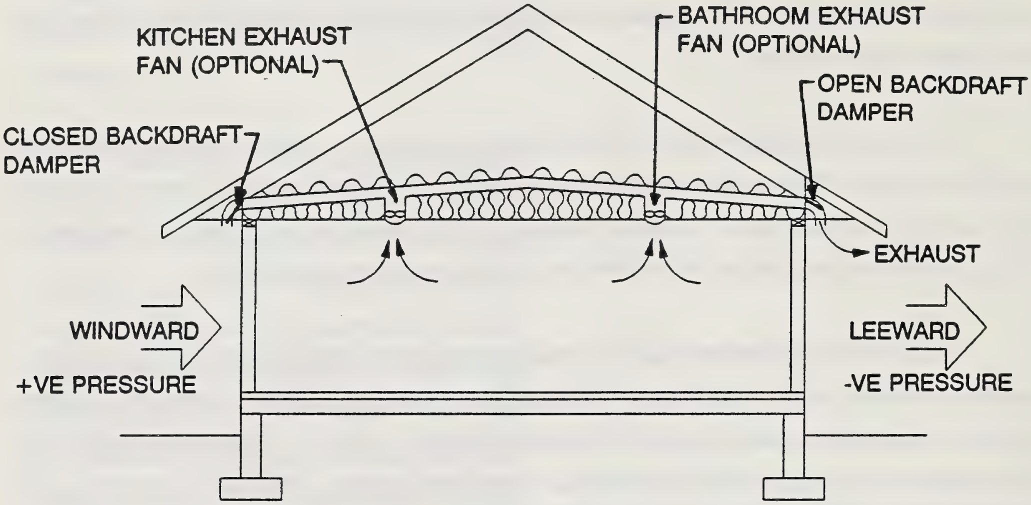
Discussions were held with a number of experts in the field of moisture movement, damage and mitigation for housing in the North. Specifically, contacts were made with Drs. C.P. Hedlin and R.S. Dumont of the National Research Council, Institute for Research in Construction (IRC), Mr. G.O. Handegord of Trow Consulting Engineers and formerly of DBR, NRC, Professor Tang Lee of the Faculty of Environmental Science, University of Calgary and Mr. J. Moorehead of Canada Mortgage and Housing Corporation. A composite of their views on moisture problems as they are apparent in northern Alberta follows.

The usual approach to solving condensation problems on interior surfaces involves the reduction of indoor humidity by ventilation with electrically powered fans and replacement of the moist air with drier outside air. However, occupants often choose to turn off the fans because of noise, the cost of operation or the extra heating cost to warm the cold fresh air.

The Northwest Territories Housing Corporation of Canada (NWTHC) has developed a semi-passive ventilation system consisting of two types of components; normal bathroom and kitchen exhaust fans directly vented to the exterior, plus several two to four inch insulated pipes connecting the exterior to the interior of the house through open crawl spaces. The room supply grilles are located high on the walls to maximize mixing of the cold supply air with warm inside air. The stack effect seems to limit fresh air intake to periods when exhaust fans are operating. As reported in Building North, October-November 1988, the system seemed to be effective in reducing odours and providing relative humidity in the 30 to 35 percent range. However, further studies indicated the system by itself was not responsible for the lower humidities. Instead it was found that a combination of ventilation strategies produced a sufficiently high air exchange rate to maintain the lower humidity, albeit with a penalty in energy consumption for space heating.

An alternate concept for a passive ventilation device illustrated in Figure 1, page 8. A lightweight pipe extending through opposite walls of a house could be installed either below or above the ceiling and fitted with standard bathroom or kitchen fan outlet vents at each exterior wall location. These vents would be equipped with simple backdraft dampers that would close under the wind pressure on a windward wall. Such backdraft dampers would remain open with a suction pressure as would be found on a leeward wall. Low power exhaust fans could also be added at the exterior vents if necessary to obtain sufficient venting. Using this setup it may be relatively easy to retrofit existing houses with moisture problems, although with some penalty in heating energy consumption and electricity. Installation in retrofit situations or where additional venting is required could run perpendicular to the roof trusses above or below the ceiling and vent through the end walls. It is also important to specify that any "horizontal" vent pipes be sloped to drain outward and covered with insulation.

Figure 1. Passive ventilation duct.



Full and efficient use of existing kitchen or bathroom fans should be a basis for any retrofit, whether or not passive or powered ventilation is going to be considered further. Existing fans should be vented, either through the horizontal vent pipe described above, or through the attic and out through the soffit area. If the soffit area is used for the outlet, backdraft dampers should also be installed at the soffit.

Moisture movement through openings and into building materials is often difficult to calculate on initial investigation, because the driving forces are hard to ascertain, whether they be for diffusion or air leakage. Vapour pressure acts across the entire width of a wall section, but the vapour pressure differential across any one element of the wall section may be unknown, yet is necessary for a proper calculation of moisture diffusion. Diffusion to a region that is below freezing is also itself still an emerging science (Hedlin 1991, ASHRAE Handbook 1989). Traditional vapour diffusion equations may overpredict the amount of moisture that can be transferred when the condensate appears as frost. Air leakage by itself is also difficult to model, and the amount of condensation that occurs along a single air leakage path can only be estimated for the simplest cases, and then only with a plethora of boundary conditions and physical parameters.

4.0 Problem Background and Site Visits

The performance of housing facilities for northern rural communities is hampered by a number of factors, encompassing the design, construction, maintenance and operation of the dwellings and limited, or non-existent community services.

The design of the houses is often based on dwellings constructed for a more urban setting, where skilled construction and maintenance personnel are available in the local community. Typically the air barrier system has not been designed or built to be continuous, impermeable, durable or structural. Further, there are generally no provisions for automatically controlled ventilation. Manually controlled ventilation is usually accomplished with windows which often freeze shut over the winter period, or open doors which cannot then be fully closed, or by passive and powered exhaust vents to the outdoors. The perimeter walls of the wood crawl spaces are designed to be insulated, and the crawl spaces are unheated. However, vents to the crawl space are often left open and the crawl space temperature drops below freezing. This in turn can result in the uninsulated floors falling below the dewpoint, and at times below freezing. Also, unvented crawl spaces may develop high relative humidities even when ground moisture barriers have been carefully installed.

Lee (1987) studied condensation problems in northern Alberta settlements and enumerated design, construction and operational factors as contributing to these problems. Occupant lifestyles, absence of plumbed water supply and sewage disposal systems, lack of ventilation systems and details of design and incomplete finishing were identified as the major causes of high humidity and destructive condensation. Recommendations on sealing attic hatches, venting crawl spaces to the outside in summer and heating them in the winter were included and the capabilities and limitations of passive and mechanical ventilation were discussed.

Focusing on houses with the most severe condensation problems, Lee (1990) retrofitted three houses with mechanical devices to reduce indoor humidity and mitigate condensation problems. In order to increase furnace fresh air intake in one house, a ceiling exhaust duct was installed and the return air grille was partially blocked to force the furnace to intake fresh air at 60 litres per second instead of 48 litres per second which was the intake prior to these modifications. It was estimated that relative humidity was lowered from an average of 50% to almost 40% in this house. In a second house, three prototypical mechanical fresh air supply systems were installed to operate in conjunction with a kitchen exhaust outlet. The result of these measures was to reduce the average humidity in the house from 60% to 40% over two heating seasons. The most successful of these operated at an air flow rate of 50 litres per second but was capable of 75 litres per second. Incoming air was preheated in the unit to 22°C at an average cost per day during the heating season of $0.41. The third retrofit was to a house heated by a wood stove and utilized a passive ventilation system that depended on the natural stack effect to exhaust air out of the house. Ceiling vents in the kitchen and bathroom were connected to an existing turbine ventilator mounted on the roof through a dehumidistat controlled damper. A duct located in the crawl space supplied outdoor air behind the wood heater. Warm air circulation from the heater to distant bedrooms was improved somewhat by cutting transoms into each bedroom. Reduction in relative humidity from an average of 55 percent to 45 percent was attributed to the ceiling venting and fresh air supply. This was not sufficient to eliminate condensation problems however, as there were 10 occupants in the house.

In order to discuss and view current construction and operation practices in northern rural housing, visits were made on December 13 and 14, 1989 to the Rural Home Assistance Program office in Slave Lake, Alberta, and to a number of houses in Chipewyan Lake and Peerless Lake, Alberta. Houses were selected for examination and potential retrofitting by staff of the Rural Home Assistance Program. Severe moisture stress, interior degradation and suspected structural deterioration were noted in each of the houses visited. Photographs taken during the site visits are included at the end of this report. Each house is heated by a wood stove and lacks both a forced air circulation system and a plumbed indoor water supply and sewage disposal system. All of the houses visited were served with electrical power, but rates were relatively high.

Conditions at Chipewyan Lake might be characterized as northern remote. The climate is severe, services are minimal and the only access is by air, except when a winter road is operational. Although year-round road access is available to Peerless Lake, its distance from any sizable community or services, and its severe climate produce conditions similar to those of Chipewyan Lake. Both communities are located in forested areas along the shores of moderately sized lakes. Although climatological data are not available for either location, both communities are at about the same latitude as Fort McMurray, Alberta, which is the closest weather station. The design heating temperature for Fort McMurray is -39°C and the average January temperature is -22°C. The average atmospheric wind speed for January is 8 km/hr (at a height of 10 metres above the ground) and the ground snow load is 1.8 kPa.

Construction of the houses appeared to follow standard design and construction practices for wood frame houses in northern Alberta. All but one house were built on wood framed crawl space foundations with footings one half to one metre below grade. Subsoil conditions at individual sites were not examined. Wall construction consisted of hardboard exterior siding, building paper, plywood or waferboard exterior sheathing, 38 x 89 mm wood stud framing, RSI 2.1 batt insulation, unsealed polyethylene vapour barrier, and hardboard interior panelling. Roof construction consisted of standard asphalt shingles, plywood or waferboard roof sheathing, prefabricated wood trusses, batt insulation, unsealed polyethylene vapour barrier, 19 mm wood strapping perpendicular to the trusses and fibreboard ceiling tiles. The roof insulation was supported by the polyethylene vapour barrier sandwiched between the roof trusses and the 19 mm cross strapping. Floor construction consisted of vinyl tiles or sheet linoleum adhered to waferboard or plywood subflooring. No insulation was placed under the subflooring between the floor joists, and although the stud spaces in the crawl space perimeter walls were insulated, no insulation was found covering joist headers.

The main source of heat for each house is a central wood stove. Temperature in the house is controlled by adding fuel to the fire when it is too cold or venting the space to the outdoors if the temperature becomes too high. Fresh air and combustion air are drawn into the house through cracks and openings in the building envelope. Heat distribution and air circulation are achieved by natural convection forces within the house, which by its nature means that there will be temperature differentials between spaces and rooms.

One occupant had installed a ceiling fan and cut transom openings over room entry doors in order to increase circulation and to foster more even heat distribution throughout the house. However, even with this form of assisted circulation, the very nature of the central wood stove heating system assures that sizable temperature drops will persist in rooms and spaces distant from the stove.

The workmanship and construction of the houses was below average for the Province, and the degree of finishing would best be described as incomplete in each of the houses visited. In particular, in each of the houses the attic hatch was unfinished and unsealed. In several houses large air gaps were visible and only hardboard or glass fibre insulation batts were covering the openings. Other ceiling penetrations for light and fan fixtures were also unsealed. Crawl space hatches from the interior were poorly finished and unsealed in some houses. As many as four vents had been installed in some crawl spaces, whereas other houses had none visible. Some of the vents were definitely open, whereas others may have been closed or blocked on the interior at the time of our visits. Slider-type window units were heavily frosted on the inside of the outer panes, with icicles hanging from outside sills and water collecting and running down the inside of the interior glass and aluminum frames.

Problems with high indoor humidity levels were evident to varying degrees in each of the houses visited. Although the weather on both days was relatively warm, most windows had ice accumulations on glass, frames and sills and/or water running down the inside of interior glass and frames. Mildew and mould was found on baseboards along exterior walls and staining of ceiling tiles ranged from sporadic to extensive in the houses.

In some areas, ceiling tiles were heavily water stained, warped and showing signs of detachment. In one house an entire row of ceiling tiles in a utility room was missing adjacent to the outside wall. It was not ascertained whether these tiles had been detached by the sagging vapour barrier membrane, or perhaps had not been installed at the time of construction. It appears that in some areas of heavy staining, moisture may have leaked down through lap joints and perforations in the ceiling vapour barrier. This moisture may have condensed in the attic space from air exfiltrating through leaky attic hatches, and/or around unsealed ceiling fans and light fixtures. Incomplete construction of ceiling exhaust fans and ducting was noted in several houses. When switched on, warm humid air is often blown into the attic, into the space above the ceiling tiles and vapour barrier, beneath the attic insulation, and into the insulation itself. During cold weather, condensation in the form of water or frost accumulates above the ceiling vapour barrier and collects in ponds in sagged areas of the vapour barrier. This in turn allows moisture to leak through any openings in the vapour barrier and puts weight on the ceiling tiles, which may cause the wetted tiles to sag or become detached from the ceiling strapping.

In several houses, moisture staining was widely distributed over ceiling areas. This type of staining appears to be caused in part by intermittent heating. While the inside air moisture content may rise rapidly after firing of the wood stove, the vapour barrier initially remains below the dewpoint temperature. The resulting underside condensation wets and stains the ceiling tiles. Also, in one house the ceiling tiles were heavily discoloured with smoke in addition to widely distributed water staining. It was not ascertained whether this was due to backdrafting of the chimney, or leakage from the stove.

Probably more hazardous to the structural longevity of the houses is the rapidly developing mildew, mould and rot of floor components in several of the houses visited. Early indications of this deterioration could be found in each of the houses at the perimeter baseboards and under furniture or other objects which block air circulation. The most advanced example of floor deterioration was found in a home where a large percentage of the floor tiles have become detached from the plywood subfloor and the subfloor surface is blackened and showing signs of softening and abrasion. Very high humidity levels in the houses and very cold subfloor temperatures, due to the absence of subfloor or joist header insulation and cold crawl space ventilation, combine to cause surface condensation on the tiles, unbonding of the tiles from the wood subfloor and, subsequently, mildewing and rotting of the floor substructure. Periodic wetting of the floor surface due to washing, clothes drying or tracked in water or snow further aggravates these problems.

Measurements of the interior conditions of similar housing near Slave Lake, Alberta were carried out under a University of Calgary study by Professor Tang Lee of the Faculty of Environmental Design, supported by the Innovative Housing Grants Program. Hygrothermographs were taken over the period January - February 1989 in a number of houses. Three of these hygrothermographs are shown in Figure 2, page 16. It is interesting to note that they all show a partial pressure of vapour of approximately 1.5 Kpa, with some variability. This corresponds to an absolute humidity or moisture content of 10 grams of moisture per kilogram of dry air, or a dewpoint temperature of approximately 14°C. Thus the moisture in the houses would begin to condense on surfaces colder than this temperature.

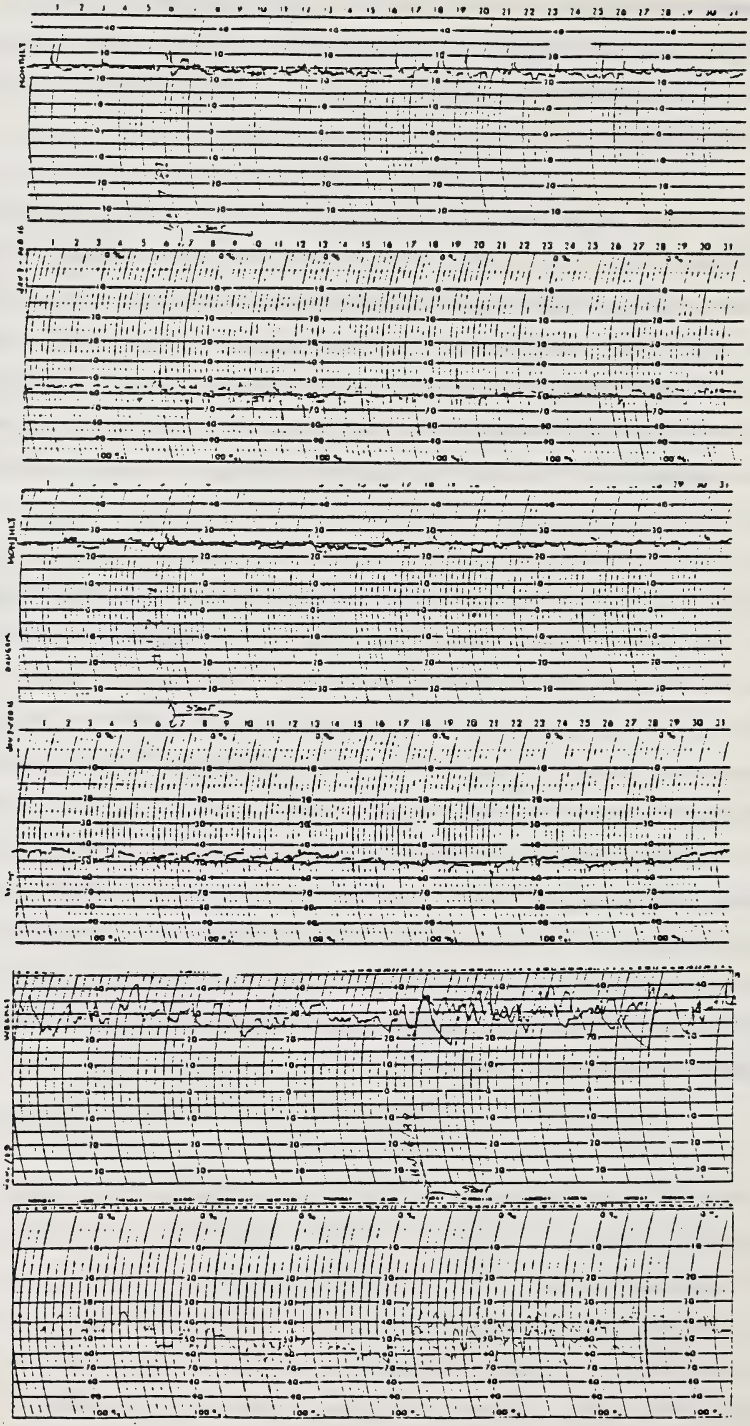
As noted earlier, hand-fired wood stove heating produces indoor environments with very large variations in temperature and relative humidity with respect to time and location within the heated enclosure. It also produces varying rates of uncontrolled ventilation in the form of exhaust air mixed with combustion gases during heating periods, and increased exfiltration up the chimney even when the wood stove is not functioning. Infiltration occurs through numerous cracks and openings in the envelope to make up for combustion requirements and exfiltration. With air exchange due to these phenomena, the houses could probably only handle approximately five kilograms of moisture generation per day, if temperatures were maintained at a constant 20°C, which is exacerbated by low insulation levels at windows and uninsulated floors, and lack of airtightness in areas where concealed condensation cannot be tolerated without degradation.

Due to the cyclic nature of heating houses using a wood stove as the primary heater, high humidities and condensation leading to elevated moisture contents of furnishings and interior finishes are a matter of course. When the temperature falls as the fire in the stove goes out, moisture is absorbed by furnishings and interior finishes. This can only be alleviated by reducing the rate of moisture generation in the house, by continuous heating and supply of outside air and/or by dehumidification and drainage by chemical or mechanical methods. Heat distribution and air circulation will also aid in maintaining a lower relative humidity in spaces far away from the heater, as air temperatures will thus not be as cold. Air circulation by natural convection forces generated around the wood stove and chimney may be aided by providing transoms and open floor plans, but some form of fan assisted circulation would be beneficial, and a ducted air supply to remote rooms even more effective.

Wide variations in heat output by the stoves result in indoor temperatures rising and falling frequently and inside surface temperatures dropping below the dewpoint temperature, perhaps several times a day. In some houses long periods of no occupancy result in indoor temperatures approaching those of outdoors. When occupancy and heating is resumed, the accompanying moisture generation can quickly result in condensation on inside surfaces and within interior materials unprotected by vapour barriers. In such a case the ventilation rate required to handle the moisture and avoid condensation would be almost infinite until surface temperatures exceed the dewpoint.

Any solution to the excess humidity problems in houses in Chipewyan Lake, Peerless Lake or other such northern communities will have to work within limits imposed by the current and future services available and normal operating procedures. Each house is heated by a wood burning stove centrally located on the main floor level, without use of a forced air circulation system. The stoves are hand stoked, with no provision for automatic fuelling. This imposes limits on the control and distribution of the heat supply to the house. Existing kitchen and utility/bathroom fans may or may not be functional and seldom if ever are used by occupants. Similarly any manually controlled ventilation or dehumidification system may not be used properly, or may be shut down due to the inconvenience of operation or misunderstanding of the necessity for such a system. The house may also be unoccupied and unheated for extended periods of time. Then, when the occupants return, it may be rapidly reheated and loaded with moisture, even though the distribution of the heat will not keep pace with the moisture loading.

Figure 2. Hygrothermographs from Slave Lake area houses (Lee, 1989).



5.0 Potential House Dehumidification and Mitigation Strategies

There are a number of solutions that can be investigated to rid the house of moisture and lower the humidity level. These include active ventilation, using mechanical or electrical means to exhaust moist air from the house and bring in cold dry air, with the possible addition of heat recovery (Heat Recovery Ventilator or HRV) to reduce the heating load associated with bringing in cold dry air. These schemes are being investigated in a companion study by Lee, and are thus outside the scope of this report. Considered herein are:

1. Passive ventilation, using changes in the pressure regime around and within the house to induce air flow through ducts and openings in the building envelope.
2. Augmenting natural ventilation through the chimney by increasing its size.
3. Wind driven active ventilation of the house.
4. Accelerated diffusion of the moisture through the building envelope to the exterior or a collection point from where the moisture can be eventually drained.
5. Collection of the moisture on cold "condensation plates" and drainage to the house waste water system.
6. Combinations and permutations of the above approaches.

With the exception of option number 4, the techniques all eliminate moisture in the space with a significant penalty in energy. Schemes to exhaust heated moist air also bring in cold, dry air. Schemes which cool the interior air to induce condensation produce similar conditions, as the temperature of the air has to be lowered to roughly the same temperatures as the ambient surface to eliminate moisture in the interior environment. Item number 4, using diffusion to eliminate moisture, carries less of an energy penalty, as only the latent heat in the air is lost.

There are a number of concerns and guidelines which can aid in deciding on a course of action. The systems to be installed have to be easily adapted to the houses. They have to be simple to install so that, if possible, local skilled or semi-skilled labour can be utilized. Maintenance requirements should be minimal or should be on a widely spaced schedule, so that maintenance can be handled by trained personnel on the sites. Operation of the systems should be as unobtrusive as possible, to minimize inconvenience and the possibility that the system may be bypassed or shut down by the occupants. Cost of installation should be reasonable and economical within the expected lifetime of the houses and the systems themselves and, finally, cost of operation, including any extra costs for heating, should be reasonable and not put undue burden on the occupants. All of these strategies concentrate on dehumidification or ridding the house of excess moisture.

6.0 Design Considerations and Theoretical Moisture Flows

For each of the potential solutions a calculation can be made of the possible moisture reduction. The average moisture conditions in the houses can be assumed to be as measured by Tang Lee in the first instance. If a lower level of humidity is to be maintained in order to reduce problems associated with the high interior humidity, the interior absolute humidity and vapour pressure must be correspondingly lower. This design level for humidity would be dependant on a number of factors related to the construction of the houses, but would most likely be limited first by the performance of the windows. This would suggest a desired relative humidity less than 20 percent at normal room temperature during winter months, which corresponds to an absolute humidity of approximately 4 grams per kilograms of dry air or a vapour pressure of 600 Pa.

For a household of two adults and two children with normal clothes drying and cooking activities, the moisture generated would average 9 or 10 kilograms per day. However, conditions seen during the site visits indicated much denser occupancies were common. Thus for a significant portion of the housing stock, and especially in houses that are experiencing severe condensation, moisture generation would be closer to 20 kilograms per day. This figure should be used as the design moisture removal rate in order to safely handle a typical severe case. The moisture will have to be removed by the potential difference between the design interior moisture level and the ambient moisture conditions. The ambient moisture conditions will be within a much narrower band due to the cold temperature and minimal moisture retention capability of the outside air, but would likely have a vapour pressure somewhere around 100 Pa, or very nearly 0 grams of moisture per kilogram of dry air.

6.1 Ventilation

Ventilation of moisture laden air to the outdoors would reduce the moisture levels by bringing in dryer outside air. The amount of moisture reduction is proportional to the volume of airflow and the difference in moisture content between the indoor and outdoor air. The equation for moisture flow due to airflow (ventilation) is:

$$WA = V\, r\, (AH_{in} - AH_{amb}) \qquad (1)$$

where:
WA = total mass of moisture transmitted by ventilation, g/s
V = volume flow rate of air, m^3/s
r = density of the interior air, kg/m^3
AH_{in} = absolute humidity of the interior air, $g_{moisture}/kg_{dry\ air}$
AH_{amb} = absolute humidity of the ambient air, $g_{moisture}/kg_{dry\ air}$

Equation (1) can be used to determine the volume flow rate of air required to vent 20 kg of moisture per day (0.23 grams per second) with an interior absolute humidity of 4 grams per kg dry air and an ambient absolute humidity very near 0 grams per kg dry air.

$$\begin{aligned} V &= WA\ /\ (r\ (AH_{in} - AH_{amb})) \\ &= 0.23\ /\ (1.1\ (4 - 0)) \\ &= 0.053\ m^3/s \\ &= 53\ L/s \end{aligned}$$

One possible route to ventilate the houses would be to use electrically powered fans. As mentioned previously this remedy is being investigated under a separate Innovative Home Grants Program study. There are many fans capable of providing the desired flow rate. If the ventilation is to be provided by passive means a calculation of the driving forces and necessary duct sizes will also have to be made.

Passive forces that are available to provide ventilation are the wind pressures around the building, the pressures due to "stack" or "chimney" effect in the house itself and the ventilation due to the wood stove chimney exhaust. Stack pressures are dependant on the height of a structure and the temperature differential between indoors and outdoors. A pressure is generated due to the difference in densities of the indoor and outdoor air, the indoor air being lighter and thus more buoyant than the outdoor air. At an outdoor temperature of -40° C and an indoor temperature of 22° C, a stack pressure of about 3 to 7 Pa can be generated in a bungalow style house with a ceiling height of 2.4 metres. The variability depends on the location of the major leaks in the building envelope and thus the level of the "neutral pressure plane" of the house. If the temperature difference between indoors and outdoors were less the stack pressure would also be less. For instance, if the interior temperature falls to 10°C and the outdoor temperature is approximately -22°C, then the stack pressure would be only about 1 to 4 Pa, again depending on the level of the neutral pressure plane. If an air flow of 53 litres per second were to be maintained with a driving pressure of 3 Pa, an opening in the building envelope would have to be:

$$A_{\text{passive vent}} = Q / C\,(DP)^{0.5} \tag{2}$$

$$= 53 / (773)\,(3)^{0.5}$$

$$= 0.040\ \text{m}^2$$

$$= 400\ \text{cm}^2$$

This corresponds to a 20 cm square, or 23 cm diameter, opening or duct through the ceiling of the house, and assumes that there is no other restriction to exhaust air flow, such as a backdraft damper,and that there is also no restriction to the infiltration of air into the house. Some form of backdraft protection would have to be used, as the duct would extend into cold regions and would allow cold air to fall down inside the supposedly exhausting duct. Also, there will be some resistance to the infiltration of air through cracks and openings in the building envelope, although an intake duct could be brought to an area near the wood stove where it would not always produce a problem of drafts. Thus the diameter of any exhaust duct going up through the ceiling would likely have to be larger than 23 cm.

Another possible method of passive ventilation would be to retrofit the chimneys on the houses to increase the amount of air flow during their operation. It was noted during the site visit that the assembly and operation of the chimneys are additional items that should be investigated by a qualified heating contractor. This is not within the scope of this project at this time and has been noted for information purposes only. During any investigation a study can be made of a scheme to increase air flow during chimney operation.

The wind that is available at the house level, to assist in active ventilation, appears to be quite minimal, although it may be able to generate more pressure than that due to stack effect alone. Except at one exposed site close to Peerless Lake, snow accumulation on roofs and around many of the houses indicated minimal wind flow around or over the houses. In particular it was noted that turbine vents placed on the roofs of many houses were inoperative, and had in fact been sheltered by deep accumulated snowfall around them. If wind were to provide some mechanical means of providing power to ventilate the houses, as from a windmill, such a device would have to be placed well above the surrounding terrain to be effective.

One of the problems associated with any ventilation is the additional heating load placed on the furnace or heater. For an average January day in Peerless Lake or Chipewyan Lake the amount of heat loss due to ventilation is:

$$\begin{aligned} Q_{vent} &= V\,r\,C_p\,(T_{in} - T_{out}) \qquad (3) \\ &= (0.053)\,(1.1)\,(1005)\,(22 - -22) \\ &= 2.58 \text{ kJ/s} \\ &= 223 \text{ MJ/day} \end{aligned}$$

This translates to an extra heating load equivalent to half a cord of firewood, at a 1990 cost of $100 to $150 per cord, for the month of January, assuming a wood stove efficiency of 50 percent which may be high. Thus ventilation would transfer some responsibility to the occupants, as the increased energy penalty would be made up by providing more firewood. There is also no provision for distribution of the dry ventilation air, although depending on the leakage pattern of the house, this may solve the moisture problem, although at the risk of providing colder spaces away from the central wood heater.

6.2 Diffusion

Diffusion of moisture through materials is dependant upon the surface area over which the process takes place, the differential vapour pressure across the building envelope assembly, the resistance of the assembly to vapour diffusion and the time available for the process to take place. The equation for diffusion through a material or assembly is:

$$WV = M\ A\ Dp \tag{4}$$

where:
WV = total mass of vapour transmitted, ng/s (i.e. 10^{-9} g)
M = permeance coefficient, ng/(s m^2 Pa)
A = area of cross section of the flow path
Dp = difference in vapour pressure between the interior and exterior, Pa.

For the present condition of the houses at Peerless Lake and Chipewyan Lake, the vapour pressure drive would be (1500 - 100) Pa, which is the difference between the interior and average exterior vapour pressures. For the condition of the houses once they achieve design levels of interior moisture, the vapour pressure drive would be (600 - 100) Pa. The movement of vapour through a building envelope assembly would depend on the permeance of the assembly at the interior before condensation starts to occur. If the assembly consisted, in its entirety, of a material such as "Tyvek" the greatest rate of moisture diffusion would be:

$$
\begin{aligned}
WV &= M\ A\ Dp \\
&= M\ (1)\ (1500\text{-}100)\ (86400\ \text{s/day}) \\
&= (6000)\ (1400)\ (86400)\ 10^{-9} \\
&= 725\ \text{g/day m}^2
\end{aligned}
$$

where the interior vapour pressure is 1500 Pa and the vapour permeance of Tyvek is approximately 6000 ng/s m^2 Pa. This is equivalent to the resistance of about 29 mm of air, or only a little more than an inch. In a more typical installation, the Tyvek would be used as part of an air barrier assembly within an exterior wall. Placing the air barrier assembly on the warm side of the wall would ensure a more stable thermal environment and keep the assembly above freezing.

Many of the houses use hardboard finish panelling on the interior. In a normal installation this must also be considered in addition to the Tyvek, with the permeance of the assembly equal to 570 ng/s m^2 Pa. The greatest possible water vapour transmission rate through the assembly would be:

$$\begin{aligned} WV &= M\,A\,h\,Dp \\ &= M\,(1)\,(86400)\,(1500-100) \\ &= (570)\,(86400)\,(1400)\,10^{-9} \\ &= 69\ \text{g/day m}^2 \end{aligned}$$

If the interior vapour pressure is to be maintained at 600 Pa, corresponding to 20 percent relative humidity at normal room temperature, then the amount of moisture flow through the Tyvek/hardboard assembly would be:

$$\begin{aligned} WV &= M\,A\,h\,Dp \\ &= M\,(1)\,(86400)\,(600-100) \\ &= (570)\,(86400)\,(500)\,10^{-9} \\ &= 25\ \text{g/day m}^2 \end{aligned}$$

Recall that in section 6.0, it was noted that the average family might generate up to 10 kilograms of moisture per day, therefore, this amount would be inconsequential to accommodate the amount of moisture generation in the houses, and indicates that diffusion in the absence of other driving forces is impractical as a dehumidification strategy.

The process of vapour diffusion through the walls of a house could be enhanced by making slight modifications to the design and construction of the wall. It was decided to analyze the moisture transmission characteristics of a wall with an interior air barrier and no vapour barrier. If the interior finish was furred out from the Tyvek so that an air space, open at the floor and ceiling levels, would permit full movement of interior air against the Tyvek, and similarly a ventilating air space was created on the exterior of the wall by furring out the siding, the resulting diffusion rate could be:

$$
\begin{aligned}
WV &= M\,A\,h\,Dp \\
&= M\,(1)\,(86400)\,(600-100) \\
&= (2000)\,(86400)\,(500)\,10^{-9} \\
&= 86\ \mathrm{g/day\ m^2}
\end{aligned}
$$

This could amount to a moisture transfer rate of 1.3 kilograms per day through a 15 m^2 end wall of a house, assuming the permeance of the furred out wall assembly is 2000 ng/s m^2 Pa. The circulation of air, the drying of insulation and additional passive ventilation that might be stimulated by solar heating and selective venting of the exterior and interior air spaces are incorporated in a proposed experimental test assembly entitled "Vapour Wall" as shown conceptually in Figure 3, page 26.

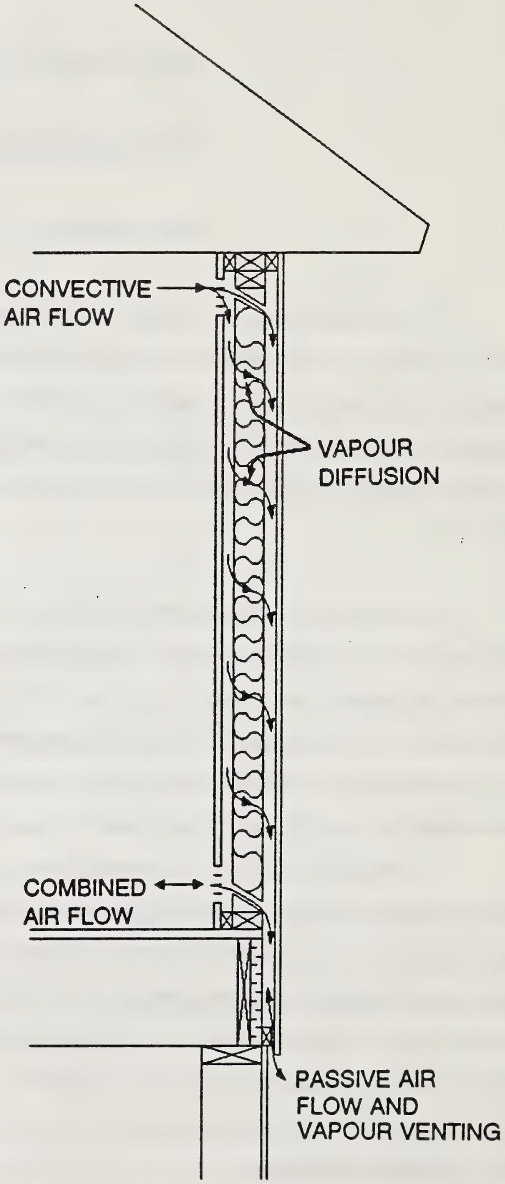
The process of moisture diffusion through a material is greatly increased when combined with heat flow in the same direction. In effect, the vapour pressure is increased and the resultant diffusion is greater than the same process working in isothermal conditions. Because accurate predictions cannot be made of the moisture transfer process when in combination with heat flow, it was necessary to set up laboratory tests to model and monitor the performance of several panel assemblies that could be realistically used in house retrofit situations (see section 7 of this report).

The effect of freezing within the wall cavity was also studied in the laboratory test simulating combined heat and mass transfer in residential walls. The relative rates of moisture transmission compared to moisture accumulation and subsequent sublimation or melting and exterior drainage are important to the continuous function of a moisture vent. The description of the test panels and laboratory test procedures used in this study are presented in section 8 of this Report, including the effect of added air pressure to aid in the operation of the moisture vent.

6.3 Condensation Plates

The use of condensation plates could be similar to the operation of a dehumidifier. In such an appliance the air may be cooled below its dewpoint so that moisture is condensed and removed from the air as water droplets or frost on the condenser plate. The amount of vapour condensation and drainage from a condensing plate depends on a number of factors. The required amount of cooling is determined from the amount of moisture which has to be eliminated from the space and is proportional to the amount of moisture generation if a constant humidity level is to be maintained. A bungalow with an interior volume of 240 m^3 and moisture generation of 20 kg per day can be assumed for calculation purposes. Using the interior design conditions (4 g/kg dry air, 24°C) the total design amount of moisture would be 1.06 kg, held in the air in the house. If the condensation plates were the only mechanism to eliminate excess humidity, the amount to be removed would be 0.83 kg/hr (20 kg/24 hr). This would mean that condensation plates would have to be designed to withdraw heat from the interior air at the rate of 3575 Watts, or 309 MJ/day at a temperature of 17°C. Additional space heat to make up for the cooling effect of dehumidification would have to be added at the rate of 3075 Watts, or 266 MJ/day, which again translates to slightly more than half a cord of wood per month.

Figure 3. Vapour wall.



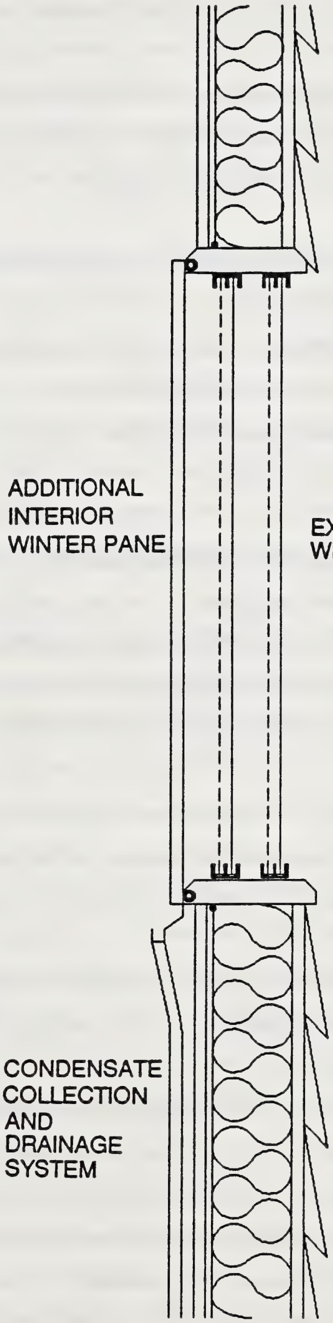
The process of forcing condensation on cold surfaces is already under way on the windows of the houses examined at Peerless Lake and Chipewyan

Lake. These surfaces are often below the dewpoint temperature of the air, and can be made to operate more effectively as condensing plates by adding an interior winter pane and collecting and draining away the condensate. A schematic of such a window retrofit is shown in Figure 4.

6.4 Combined Heat and Mass Transfer

Researchers have long recognized that moisture transfer through building materials is more complicated than predicted by early diffusion mathematical models and test methods. "Water exists and moves in several phases by many often simultaneous transport mechanisms. As water vapour, it moves by diffusion or convection. Diffusion takes place under the influence of a vapour concentration gradient and convection involves the movement of water vapour with air flows. In practice, movement by convection usually dominates. Relatively small air flows can deliver large quantities of water, especially when compared to other transport mechanisms" (Ten Wolde, 1989). While standard test methods have yet to be developed to determine the influence of temperature gradient and moisture content on moisture transfer, measuring the air flow through a building component can determine the associated moisture transport with relative ease.

Figure 4. Window as condensation plate.



7.0 Laboratory Testing Program

7.1 Concepts Selected for Laboratory Testing

A testing program was developed to evaluate the rates of water vapour transmission for various combinations of air barrier systems and insulations. The following test panels and test vents were selected for laboratory testing:

1. Air barrier instead of a vapour barrier on the warm side of stud space insulation, Test Panel No. 1, Figure 5.1;
2. Air barrier on warm side and insulating sheathing over the outside of studs and insulation, Test Panel No. 2, Figure 5.3;
3. Insulating sheathing with air barrier on the warm side of stud space insulation, Test Panel No. 3, Figure 5.5.

It was observed in the first three tests that much of the frost had accumulated in the upper portion of the cold-side insulation or on the surface as hoarfrost. It was therefore decided to place a 178 mm wide, 50 mm thick piece of glass fibre insulation board at the top of the stud space with fibre orientation parallel to the vent and moisture flow, in the expectation that it would channel and facilitate vapour transmission through the panel.

4. Phase 1: Air barrier on warm side of RSI stud space insulation and glass fibre insulation board as described above installed at the top of the stud spaces.

   Phase 2: The air barrier was removed over the warm side of the glass fibre insulation board vent.

   Phase 3: The panel configuration was unchanged from Phase 2 of the test, but on air pressure differential of 5 Pa was applied across the panel from warm to clod sides. See Figure 5.7.
5. Test No. 5 was designed to measure the air flow rates through another vapour vent construction of conventional glass fibre insulating sheathing material, folded and compressed from 76 mm to 50 mm thickness by forcing into a 50 mm deep space formed with an additional stud spacer installed 50 mm below the top plate. As in Phase 3 of Test No. 4 the glass fibre orientation in the vent was parallel to heat flow and the air pressure differential was 5 Pa across the panel from warm to cold sides. See Figure 5.9.

7.2 The Environmental Test Chamber and Instrumentation

An environmental chamber from Dexon Canada Manufacturing Corporation, Calgary, Alberta was modified to produce a cold, dry environment and a warm, humid environment separated by an insulated and air sealed test wall into which panels could be installed. An entry lock separating the cold and warm environments permitted access with minimum heat or moisture transfer. Entry doors into each compartment were weather stripped and double sealed with tape.

The test wall was built to provide a thermal resistance of at least 4.1 m^2°C/W. It was air and vapour sealed with two layers of 6 mil polyethylene, double caulked at all joints with adjoining walls, floor, ceiling and openings for doors and the test panel. Both sides of the test wall were covered with 16 mm oriented wafer board. An opening to receive a 600 x 600 mm test panel 92 mm or thicker was provided in the wall. Each time a panel was installed, the joints between panel and frame were packed with EPDM tube and double taped. A vapour seal over the opening was taped shut and a dummy panel was inserted in the test frame whenever panel changes were made to prevent leakage between environmental chambers and to maintain steady conditions on each side.

The cold side refrigeration system was adjusted until capable of maintaining -32 ± 2°C continuously for six hour periods, and, following a short defrosting cycle, to return quickly to the above conditions. The warm side heater and humidifier were capable of maintaining thermostat set points ± 1.0°Cin the mid 20°C range and humidistat set points ± 2%R.H. in the mid 50% relative humidity range.

Temperatures were measured in both chambers and through the test specimens with thermocouples connected to an electronic data logger. Hygrothermographs recorded relative humidity and atmospheric temperatures in the two chambers. Air flow through the test vents was measured with a hot wire probe and thermo-anemometer. An air pressure differential of 5 Pa was maintained across the test wall by a make-up air unit during the pressure testing of vents. Moisture transmission through, and water and frost condensation within test specimens was measured by weighing with an electronic balance.

7.3 Wall Vapour Panels and Vents

Test panels were framed with construction grade 38 x 89 mm lumber. Panel dimensions were 600 x 600 mm, divided vertically with a 38 x 89 mm stud to simulate a standard 400 mm stud spacing. The insulation board and air barrier materials were placed in or on the panel and, where necessary, were supported in place by a nylon netting fastened to the frame. The stud space insulation was RSI 2.1 friction fit glass fibre insulation, as commonly used in wood frame walls. The air barrier membrane was spun-bonded polyolefin (SBPO) with a permeance of 6000 ng/s Pa m^2. The insulating sheathing, when used, was RSI 1.18 38 mm rigid resin bonded glass fibre board with a factory applied, moisture resistant facing paper with a permeance of 1723 ng/s Pa m^2, The insulation board used in Test Vent No. 1 was RSI 1.5 50 mm rigid glass fibre board without any facing material. The compressed insulation board used in Test Vent No. 2 used two layers of 38 mm insulating sheathing laid back to back, with the facing paper outside. The boards were compressed to a thickness of 50.8 mm.

7.4 Discussion of Laboratory Test Results

The laboratory test program explored the moisture transmission capabilities of various assemblies of glass fibre insulation and spun-bonded polyolefin (SBPO) membrane. The SBPO acted as an air barrier in panels intended to permit diffusion of water vapour; without the SBPO air barrier the panels functioned as vents permitting limited air flow with the vapour transmission.

7.4.1 Test Panel No. 1

Figure 5.1 Profile and section of Panel No. 1.

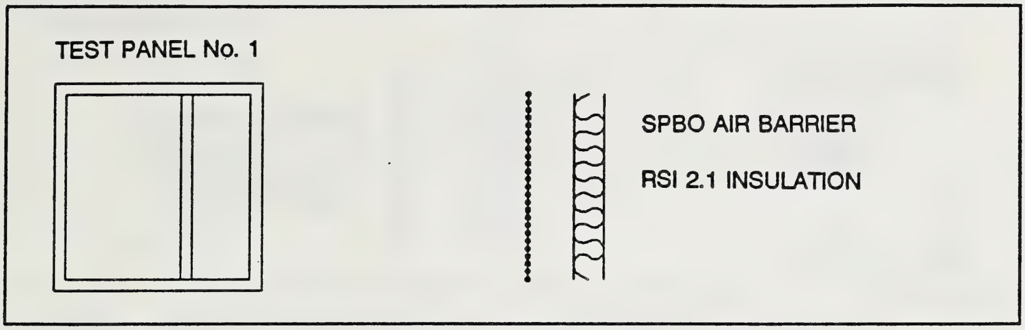
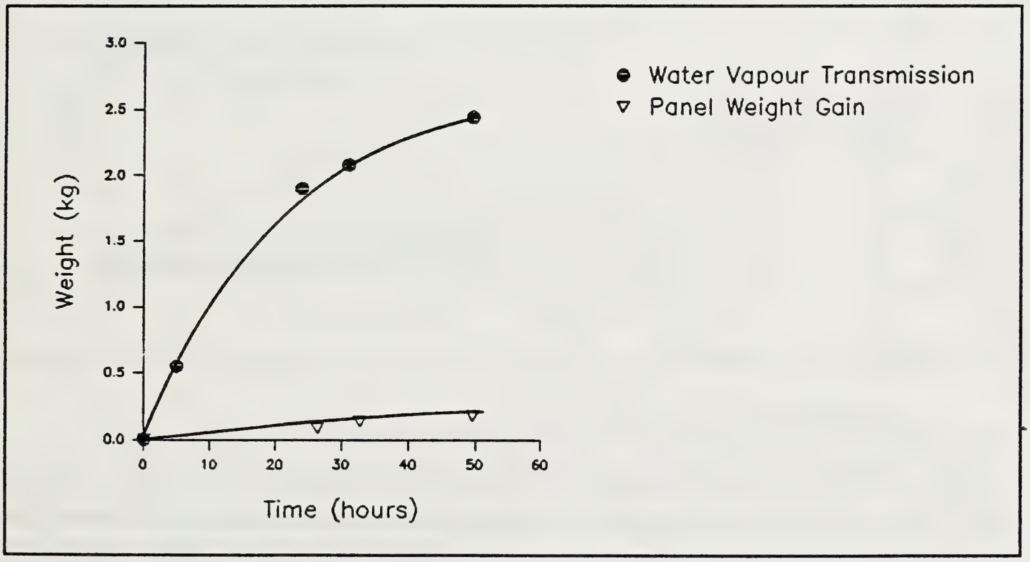


Figure 5.2 Water vapour transmission through, and moisture accumulation within Test Panel No. 1.



With the SBPO air barrier on the warm side of RSI 2.1 stud space insulation, rapid water vapour diffusion through the panel and rapid accumulation of frost in the insulation quickly indicated that the assembly would not be a practical combination for wall or ceiling construction in regions of long, continuously very cold weather.

7.4.2 Test Panel No. 2

Figure 5.3 Profile and section of Panel No. 2.

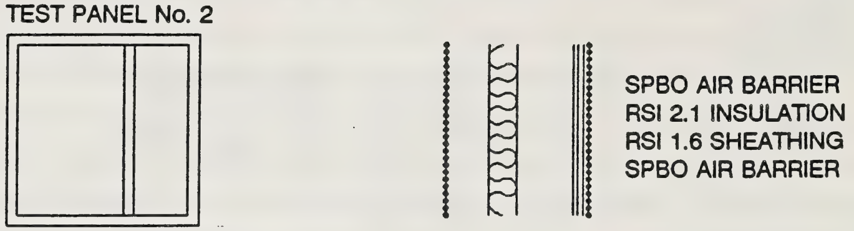
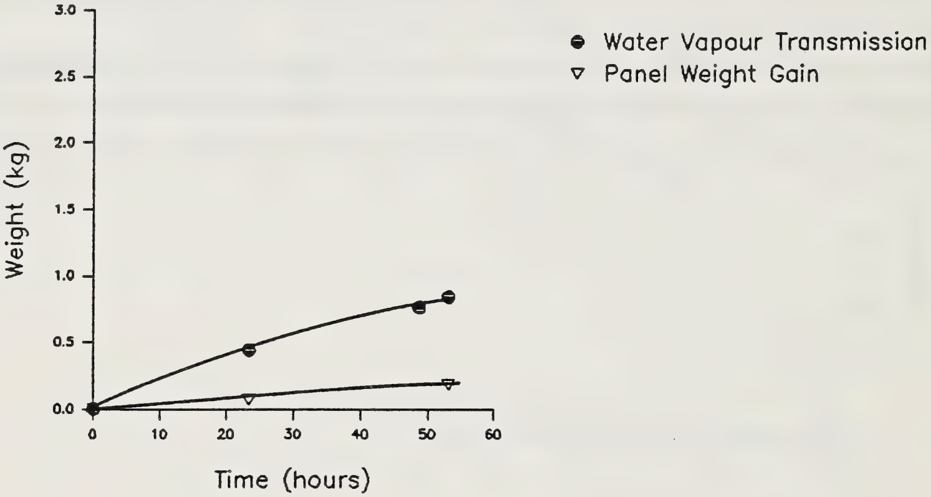


Figure 5.4 Water vapour transmission through, and moisture accumulation within Test Panel No. 2.



With the SBPO air barrier on the cold side of RSI 1.6 exterior insulating sheathing over studs and a SBPO air barrier on the warm side of the RSI 2.1 insulation and studs, the water vapour transmission rate was reduced to approximately one third of that for test panel No. 1. The rate of frost accumulation in the stud space insulation was also greatly reduced, but the rate of frost accumulation in the insulation sheathing averaged at 5.7% increase in weight per day. The total weight gain of Test Panel No. 2 was similar in magnitude to that of Test Panel No. 1.

7.4.3 Test Panel No. 3

Figure 5.5 Profile and section of Panel No. 3.

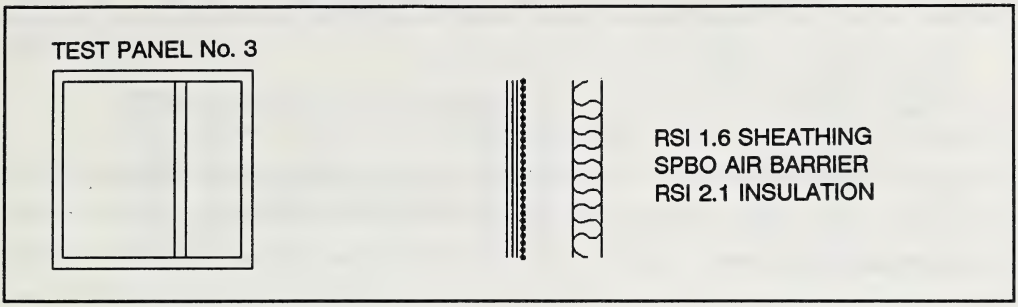
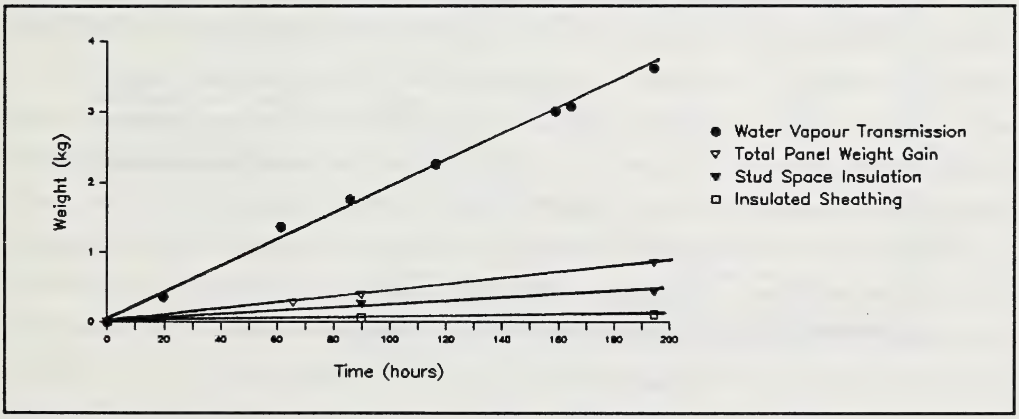


Figure 5.6 Water vapour transmission through, and moisture accumulation within, sheathing and stud space insulation of Test Panel No. 3.



With the SBPO air barrier located between RSI 1.6 warm side insulation and RSI 2.1 on the cold side, the rate of water vapour transmission through the panel continued throughout the test at a rate averaging 1.48 x 10^{-3}ng/s m^2 (1.276 kg/day m^2). The warm side insulation experienced insignificant moisture increase and the cold side insulation almost doubled its original weight with frost build-up over an eight day test period.

7.4.4 Test Panel No. 4 with Vent No. 1

Figure 5.7 Profile and section of Panel No. 4 with Test Vent No. 1.

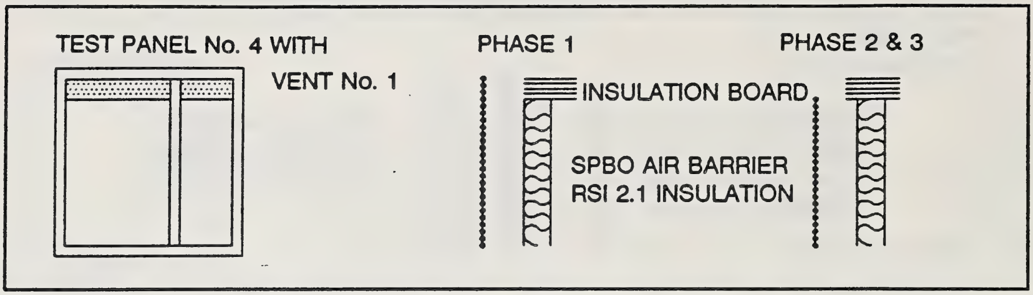
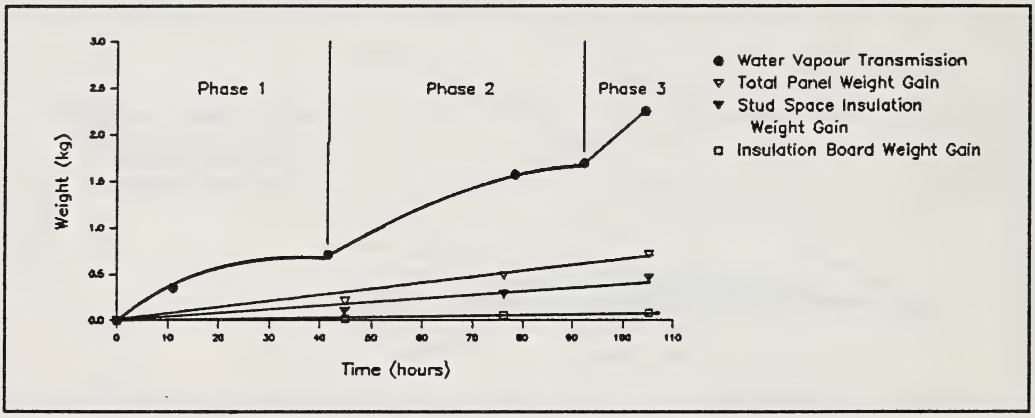


Figure 5.8 Water vapour transmission through, and moisture accumulation within Test Panel No. 4, which includes Test Vent No. 1.



In phase 1 of Test No. 4 with a full SBPO air barrier on the warm side of the panel, the average vapour transmission was found to be 1.26 x 10^{-3} ng/s m^2 for the panel, which was very similar to that found for Panel No. 2.

In phase 2 of Test No. 4 the SBPO was removed from the upper area covering the warm side of the glass fibre board vent. The vapour transmission rate increased almost 20 fold to 2.30 x 10^{-2} ng/s m^2. The insulation board gained in weight at the rate of 2.35%/day and stud space insulation gained at the rate of 14.4%/day.

In phase 3 of Test No. 4 the panel was unchanged from the phase 2 test, but an air pressure differential of 5 Pa was applied across the panel. During this period the water vapour transmission almost doubled again above the neutral pressure results found in phase 2. The average rate of vapour transmission through the panel was 3.76×10^{-2} ng/s m^2. During this phase the insulation board gained in weight at the rate of 1.92%/day and the stud space insulation gained at the rate of 10.6%/day.

At the end of the 7.9 day duration of Test No. 4, the insulation board used as the upper vent had increased in weight by 16.8% and the stud space RSI 2.1 insulation had gained in weight by 98.1%. When removed from the test panel, the stud space insulation appeared to be heavily filled with frost while the insulation board remained light and unblocked. When allowed to thaw at room temperature the stud space insulation released most of the thaw as run off water. No water was collected from the vent insulation board as it thawed. Presumably the moisture was held hygroscopically until it evaporated and left the board as vapour. Near the end of the test the vapour transmission rate remained at 3.26×10^{-2} ng/s m^2 and the air flow rate was measured to be 5.25×10^{-2} litres per second through the vent (ie) 0.283 litres per second m^2. Translated into terms of vapour vented per day and the accompanying air changes ventilation for a house of 200 m^3 volume, the 363 mm wide and 50 mm deep vent transmitted approximately 0.69 kg of moisture per day with an accompanying exfiltration of less then 4 percent of the volume of the house per day at a pressure differential of 5 Pa. The latter is the average of the pressure differentials discussed in section 6.1 of this report. It represents a reasonable pressure differential near the ceiling of a moderately air-tight house under full heating during winter conditions. Wind pressures on the exterior may increase, decrease or, at times and in certain orientations, reverse the air pressure gradient. With the air permeability of the vent as low as it is any reverse flow due to high wind pressures should not produce noticeable inside drafts if the vent is placed high on the wall.

7.4.5 Test Panel No. 5 with Vent No. 2

Figure 5.9 Profile and section of Panel No. 5 with Test Vent No. 2.

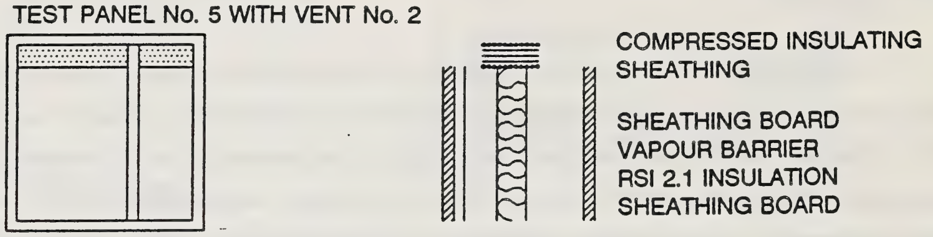
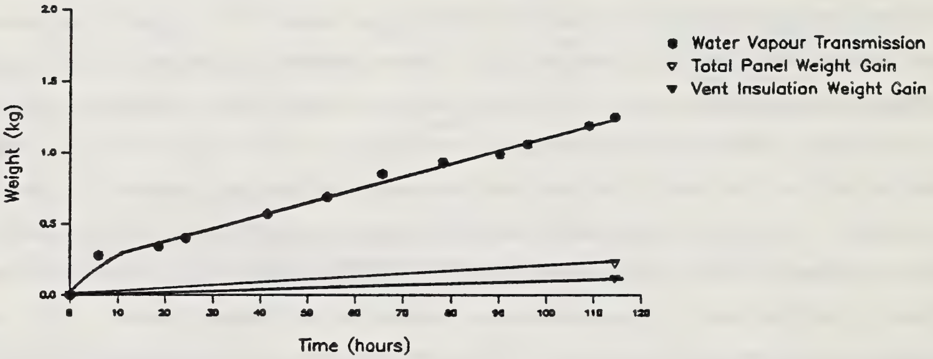

TEST PANEL No. 5 WITH VENT No. 2
COMPRESSED INSULATING SHEATHING
SHEATHING BOARD
VAPOUR BARRIER
RSI 2.1 INSULATION
SHEATHING BOARD

Figure 5.10 Water vapour transmission through, and moisture accumulation within Test Panel No. 5, which includes Test Vent No. 2.



Test No. 5 was designed to measure the air flow rates through another vapour vent constructed of readily available glass fibre insulating sheathing material, folded and compressed from 76 mm to 50 mm thickness and tightly fitted into a 50 mm deep slot formed below the top plate between wall studs. Because it had SBPO air barrier bonded to one side, it was relatively easy to tape the air barrier at the top and bottom of the vent to the existing vapour barrier on the face of the panel and on the face of the surrounding wall. For this test the only vapour and air movement was through the 50 mm x 365 mm vent cross section. As shown on Figure 5.10 the average vapour transmission rate during the 4.8 day test was 8.38×10^{-3} ng/s m^2 and the air flow rate at 5 Pa near the end of the test was 1.30×10^{-2} litres per second m^2. The vent insulation weight gain was 4.2%/day.

8.0 Proposed Field Trials

The previously described results from Phase #3 of laboratory Test No. 4 indicate that properly oriented glass fibre insulation board will operate as a venting medium, permitting the passage of water vapour to areas of lower vapour pressure. It is proposed to use this capability in residential wall vents which will transmit excess moisture from a warm moist house to the cold but drier outside air. This concept has yet to be proven outside the confines of a closely regulated laboratory setting. The following research proposal outlines how this concept might be pursued in typical northern houses which were the focus of this study.

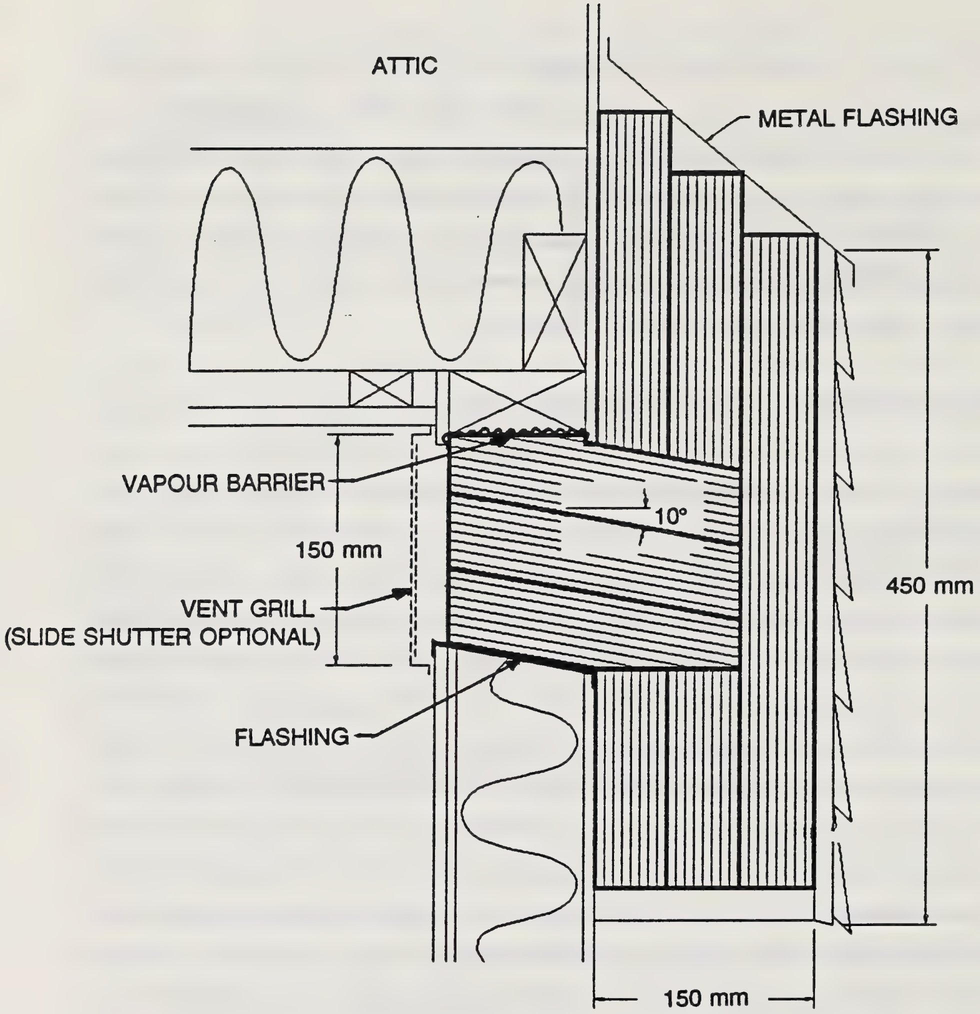
8.1 Passive Dehumidification Through Wall Vapour Vents

Based on the field investigations associated with this project and the observations noted in Lee's work, 1991, it would appear that a need exists for a simple, passive venting mechanism, which can handle the moisture load generated in a typical 100 sq. m. northern bungalow. The mechanism should be capable of venting upwards of 15-20 kilograms of water per day when indoor and outdoor temperatures are in the range of +25°C and -30°C respectively. The principle of operation is mainly passive, that is, it is driven by the existing stack effect of the heated house with or without wind pressures. Stack effect should typically produce 5 Pa across the building envelop. It is proposed that for the typical home, such as those viewed in the Peerless and Chipewyan Lake areas, a total of 12 stud spaces be fitted with a 150 mm vapour vent. The vent orientation for the glass fibre board and general construction details are illustrated in Figure 6, page 38. The vents should be distributed throughout the homes in the following manner: 3 stud vents in each of the living room and kitchen, 2 stud vents in the laundry/utility room and one stud vent in each of the other occupied rooms in the residence. Based on extrapolation from the laboratory test results, it is estimated that this combination of vents would extract 16.5 kilograms of water vapour per day while permitting an air-flow of 2.45×10^5 litres per day. At this extremely low flow rate of only 1.25 air changes per day the air-flow would be essentially undetectable to residents and result in no discomfort. A typical elevation view for an end wall installation of vapour vents is shown in Figure 7, page 39.

8.2 Monitoring

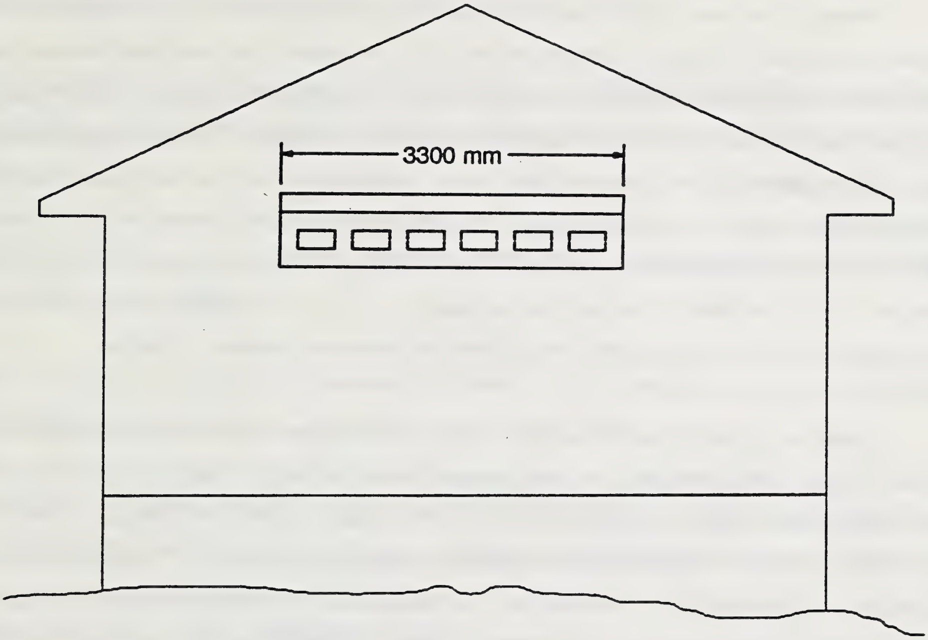
Naturally, for those who wish to attempt a formal evaluation of the vents through analysis of environmental conditions it would be necessary to record humidity, energy consumption, family

Figure 6. Passive vapour vent.



composition and weather conditions over a minimum of two years, each one covering a pre- and post-installation heating season. However, as documented by this study, there have been extensive recordings, site observations and anecdotal information gathered on homes in the area. While not precise, it is felt that this base information represents a viable datum against which the effectiveness of the vents might be judged. This position is further reinforced when one acknowledges that family living patterns and the weather are in themselves highly variable; consequently, year to year comparisons are at best tentative; therefore, it is proposed that the test vent configuration be monitored over only one heating season for a period of 7 or 8 months from September to April.

Figure 7. Vapour Vents. Typical installation in end wall for living room and kitchen.



Monitoring should record indoor temperatures and humidities with hygrothermographs. It would be helpful if external temperatures and wind speeds could also be recorded although local weather data would be acceptable input. Equally important in evaluating the effectiveness of the concept will be the anecdotal information gathered from the host family regarding their perception of increase or decrease in humidity indicators such as window frost, mold growth and moist sills and walls. This information can be reinforced by periodic site visits of local housing officials to view the condition of the vents themselves.

9.0 Conclusions

Although the work in this project focused on the development and evaluation of moisture removal techniques, it would be inappropriate to not recognize that they exist within a broad environment of residential moisture reduction and control strategies. Obviously, if less moisture is generated then less effort must be expended to control it. Similarly, if building envelopes and glazing have high insulation values and good vapour barrier characteristics there is less chance for surface condensation and interstitial damage. These matters have been covered extensively in other reports, and many excellent documents are listed in the bibliography; however, even with good moisture control practices it will still be necessary to vent some excess moisture from most contemporary homes, and it is within this context that one must consider this work.

Based on the site visits and laboratory tests it would appear that properly oriented glass fibre insulation board vents could be a valuable moisture control strategy. The vents offer the potential for considerable moisture extraction with very little penalty in terms of energy consumption. Furthermore, the vents would be easy and extremely inexpensive to install. They lend themselves to both new and retrofit applications and are compatible with existing construction practices and housing styles. Finally, because the venting is driven by natural forces, the system is energy conserving and free of potential mechanical failure. Given these attributes, it would appear that vapour vents could be a viable dehumidification solution.

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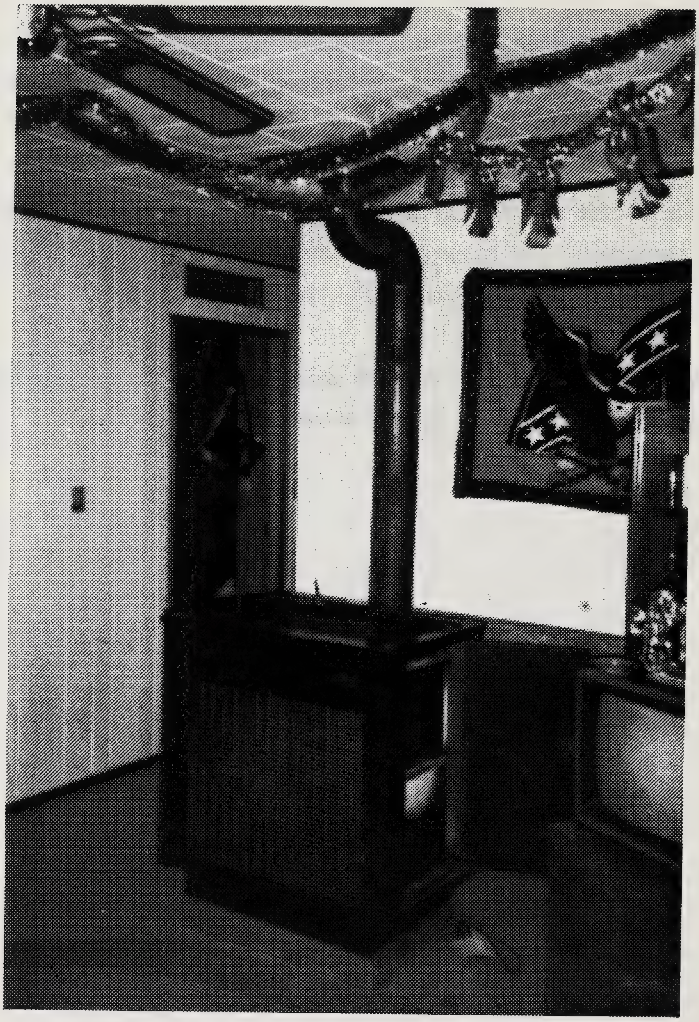
Appendix A, Site Visits to Chipewyan Lake and Peerless Lake

A.1 Report of Site Visits

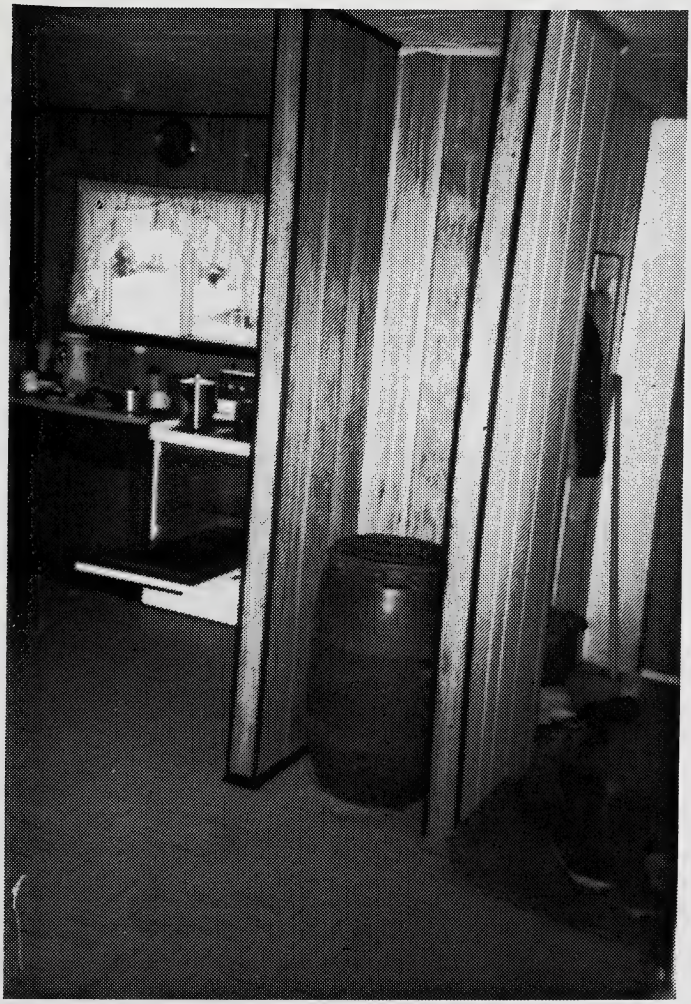
In order to discuss and view current construction and operation practices in northern rural native housing, visits were made to the Rural Home Assistance Program office in Slave Lake and to a number of homes in Chipewyan Lake and Peerless Lake, Alberta on December 13 and 14, 1989.

During the inspection tour of a number of houses, evidence was noted of previous severe moisture stress and interior degradation, and ongoing deterioration of the interior finish and structure. Photos taken at the time of the visits are included at the end of this Appendix.

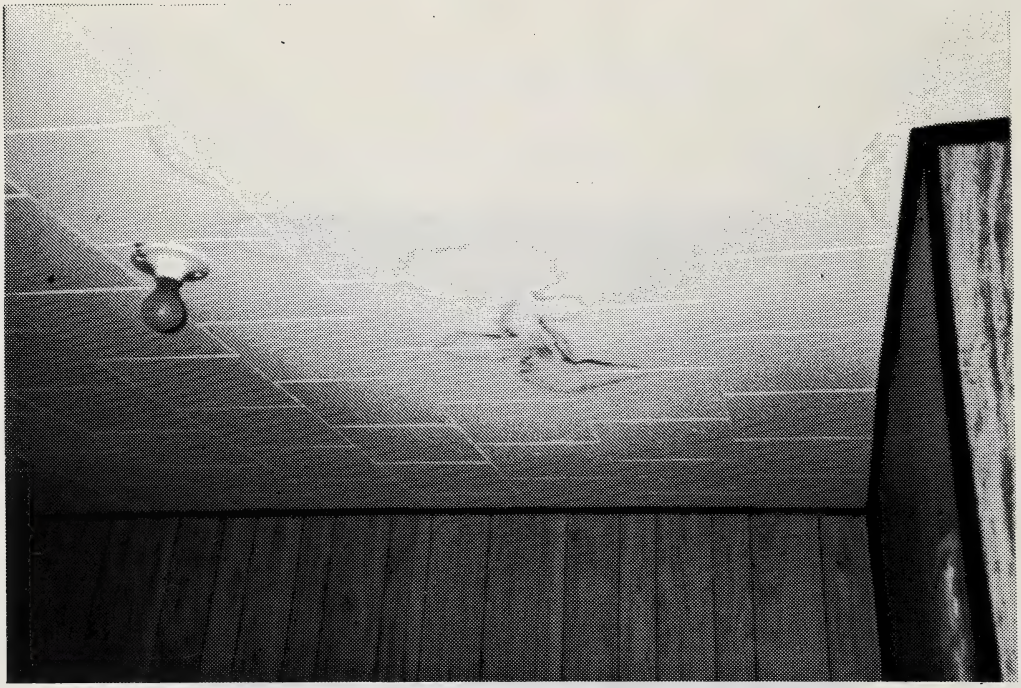
The extent of the problems and the contributing factors of occupancy loading and lifestyle factors are discussed in considerable detail in Section 4.0 of the report.



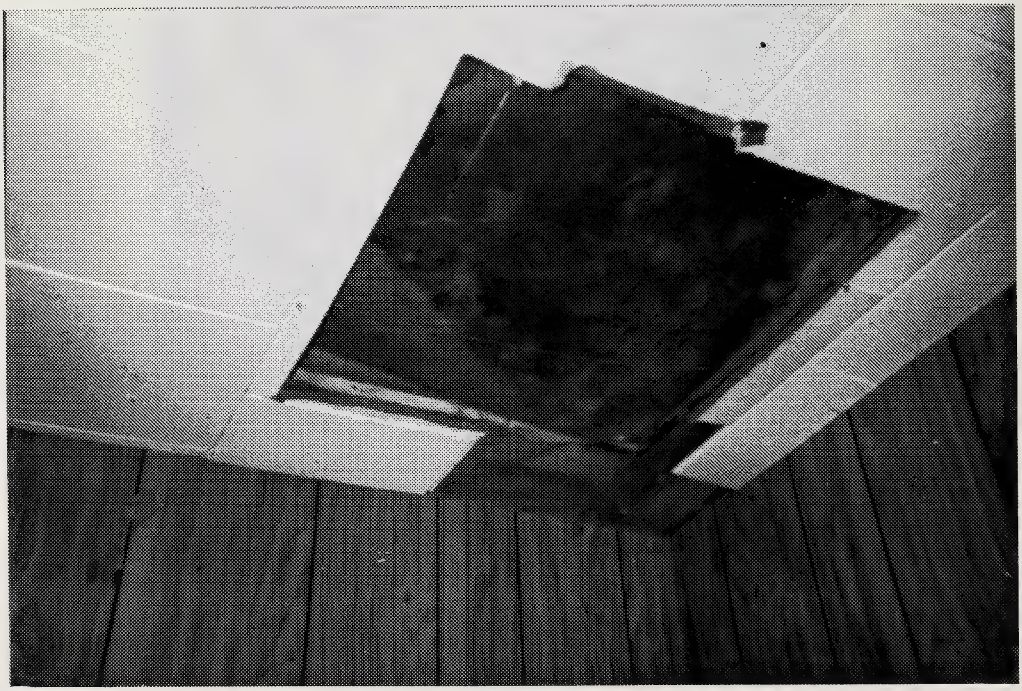
Typical wood stove heater and chimney.
Ceiling fan and transom installed by occupant.



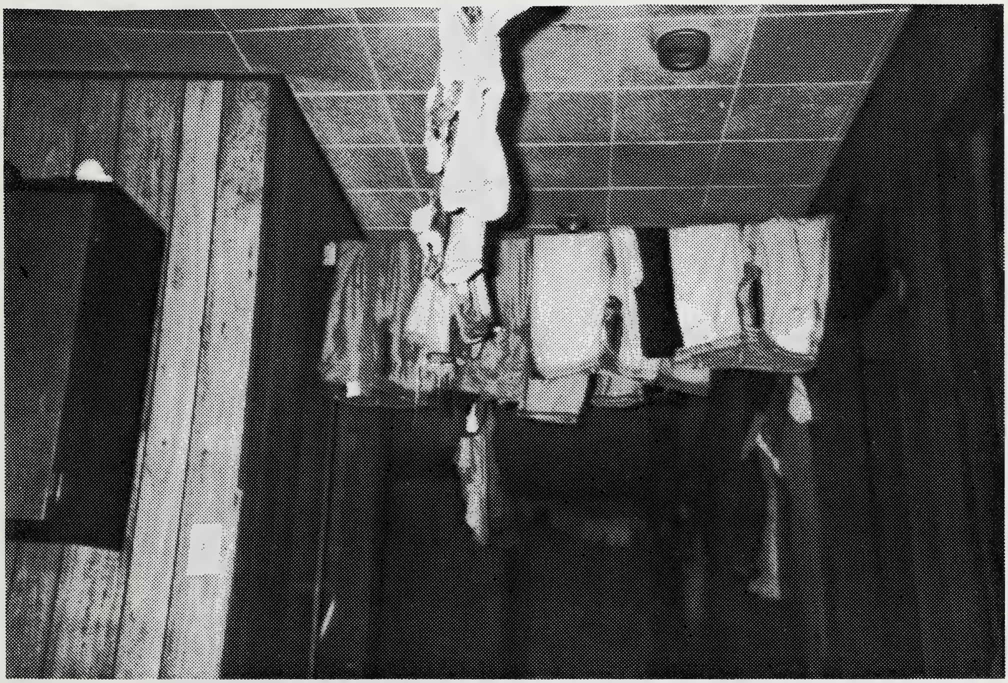
Kitchen, water barrel and front entry.



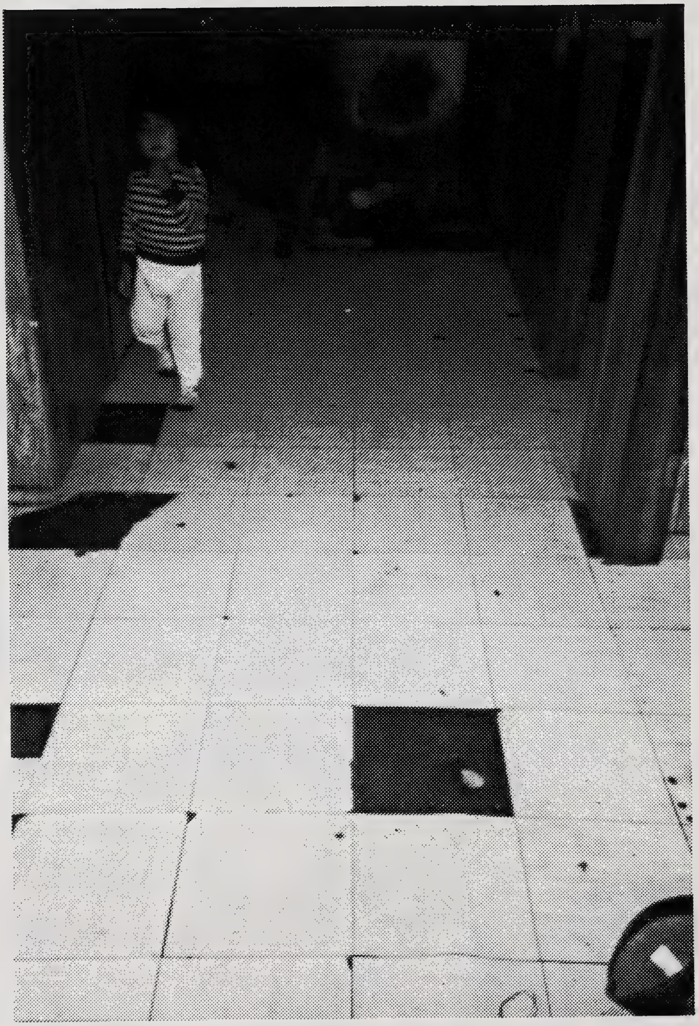
Ceiling tile stains.



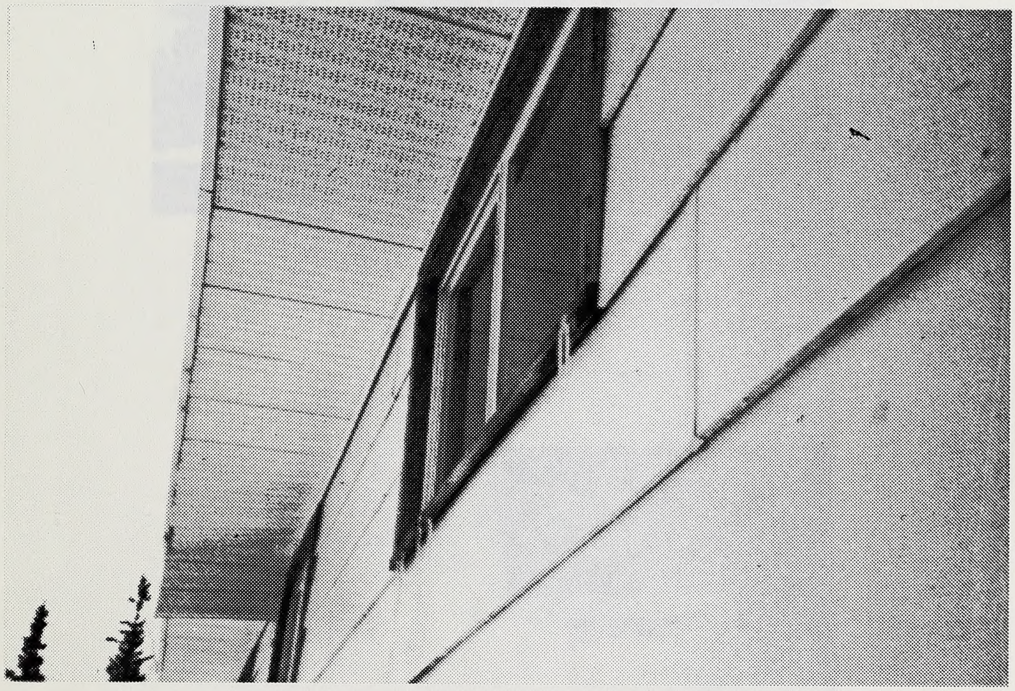
Unfinished attic hatch.



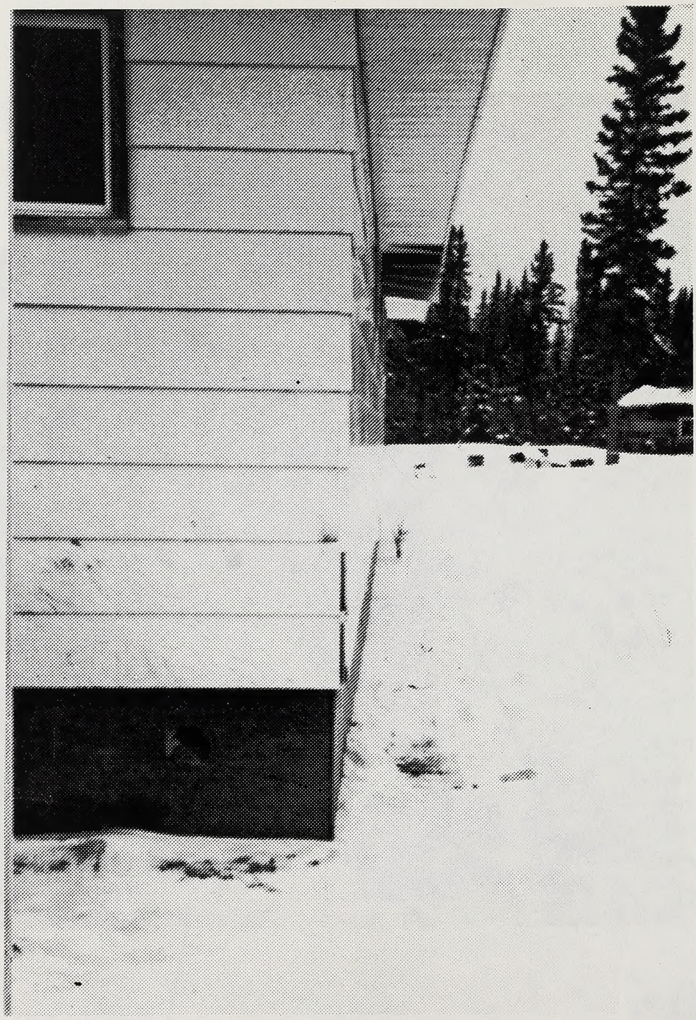
Generally discolored ceiling tiles, several loads of laundry drying on indoor clothes line.



Many floor tiles missing, chipped warped and unbonded from plywood subfloor.



Icicles on unpainted window sill, detached soffit panels.



Icicles on window sill, detached soffit panels, no vents installed in crawl space, hole punched in outer sheathing.